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WHEELCHAIR MOVEMENT CONTROL USING TONGUE DRIVEN WIRELESS ASSISTIVE TECHNOLOGY

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ABSTRACT

Tongue driven system is a new wireless assistive technology for the persons severely disabled due to spinal cord injuries, quadriplegia or repetitive strain injuries (RSIs). It is a tongue operated non-invasive or minimal invasive, unobtrusive and effective technology. It helps users to control many devices in their environment using their unconstrained tongue motion. Tongue driven system consists of an array of Hall Effect magnetic sensor and permanent magnet. A small permanent magnet is held on the tongue using tissue adhesive or tongue piercing. The magnetic field generated by the magnet will vary around the mouth as a result of tongue movement. These variations are sensed by an array of magnetic sensors mounted on the headset outside the mouth. The sensors outputs are wirelessly transmitted to the microcontroller. Microcontroller will process the signals to control the movements of the cursor on a computer screen or to operate a power wheelchair. This technology provides faster, smoother, and more convenient control.

KEYWORDS: Assistive Technologies, Quadriplegia, Environmental Control, Hall Effect Sensors, Tongue Motion

INTRODUCTION

Quit a good number of people is severely disabled due to spinal cord injuries, quadriplegia or repetitive strain injuries (RSIs). Quadriplegia results in the partial or total loss of the sensory and motor functions of all limbs. Hence it becomes tedious for such persons to carry out their work in day to day life without continuous assistance [1]. It is estimated that the number of people in United States who have spinal chord injury and are alive in 2012 has been estimated to be approximately 270,000 persons. It is estimated that approximately 12,000 new cases of spinal chord injury occurs each year. Since 2005, the average age at injuries is 41.0 years. The majority (90%) of SCI individuals survive and live near-normal life spans. Spinal chord injury can occur due to various reasons like motor vehicle crash, falls, act of violence, sports *etc* [2].

Power wheelchair plays the key role in severely disabled person’s life as they completely depend on the wheelchair for moving around in home, office and outdoor environment. Normally, the movement of wheelchair is controlled by operating the joystick, but for doing so upper limbs should have certain level of physical movement, which people with severe disabilities may not have. Hence researcher developed some assistive technology which enabled user to operate or control the devices that they were previously unable to operate or find hard to operate, by providing changing method of interacting with device depending on the remaining abilities in the user like head movement, eye position, muscular activities or neural signals. Assistive technology not only helps the user to effectively control their environment, thus reducing the workload of family member or dedicated caretaker and reducing their healthcare costs, but may also help them to be employed [1]. Due to this they will experience energetic, independent, self supportive and fruitful life. A number of assistive technologies have been developed to access personal computer, telephone, television or for driving power wheelchair. In these entire technologies computer plays the role of interface between the user and his intended target, such as power wheelchair, robotic arm, telephone or television [1]. Assistive technology devices that are controlled

by switches are large in number. The switch integrated hand split, diaphragm control system, chin control system and electromyography switch are all switch based systems and the degree of freedom offered by such system to the user is confined [3]. A group of head mounted assistive technology has been made for the persons who have certain kind of neck or shoulder movements. This technology is mainly used to make devices that imitate computer mouse using head movement. The main limitation of these systems is that it constantly requires neck or shoulder movement which is tiring and uncomfortable for the user [3]. Researchers have developed various assistive technologies based on tracking eye motion from corneal reflection, pupil position or electrooculogram potentials. The main drawback of this technology is that eye is a part of sensory cortex and not of motor cortex therefore extra eye movements affects the normal visual activities of the users [4]. There is considerable ongoing research on the series of assistive technologies which consist of Brain Computer interfaces. This neuro-technology has helped the users who cannot benefit from mechanical movement of any body organs. This system control the external devices by detecting user's intention by utilising electric signal originated from brain waves [5]. Brain Computer interfaces technology cannot be used for controlling the power wheelchair because the response time of the system is large. Voice controlled mechanism can also be used to operate power wheelchair by the individual who can produce consistent and distinguishable voice. Speech recognition system is used in this technology for taking voice of the user as the input signal. Speech recognition system has to be trained before using it for actual control of the wheelchair. The limitation of this system is that, due to slow signal processing user cannot do the frequent changes in the position of wheelchair in the crowded environment [6].

Out of all these assistive technologies which were developed, very few assistive technologies has been proved successful in outer environment rather than in research laboratories. There are various technical and psychophysical factors which affect the acceptance rate of an assistive technology that are system should be easy and convenient to operate, device should require less time to learn, it should be cosmetically suitable; device should be portable, unobtrusive, minimum or non-invasive [3].

The assistive technology can also be made with the help of tongue, where devices can be controlled by tongue movement. Tongue is the good alternative to operate the system because unlike hands and feet, which are controlled by the brain through spinal cord, the tongue is connected to the brain via hypoglossal nerve that generally escapes damages in severe spinal cord injuries or neuromuscular diseases [3]. It is also the last to be affected in the neuromuscular degenerative disorders. Another advantage of using tongue as an input is that tongue occupies an area in the sensory and motor cortex in the human brain as big as the one of finger which shows equality in the ability of tongue and mouth with that of the fingers and hands [3]. Therefore tongue movement is fast, accurate and do not require much thinking, concentration or efforts. Also there is similarity between tongue muscle and heart muscle hence it does not fatigue easily [1]. Therefore a tongue based device can be used continuously for several hours. The tongue can be comfortably moved by the user at the resting position hence this system is advantageous for such people who are not able to sit for long time as they can operate device at resting position also. The above reason has resulted into the development of Tongue driven system.

The objective of this paper is to develop a system that is minimal or non invasive unobtrusive, easy to use and learn that can replace some of the arm and hand functions.

SYSTEM ARCHITECTURE

System Overview

The generalized block diagram of tongue driven wireless technology is shown in Figure 1. The block diagram can be divided into two sections that is transmitter section and receiver section. Transmitter section consists of three Hall Effect

sensor (HS1, HS2, HS3), microcontroller unit, RF transmitter and power supply. While receiver section consists of RF receiver, microcontroller unit, dual full bridge driver, power supply and DC motor namely Left Motor (LM), Right Motor (RM).

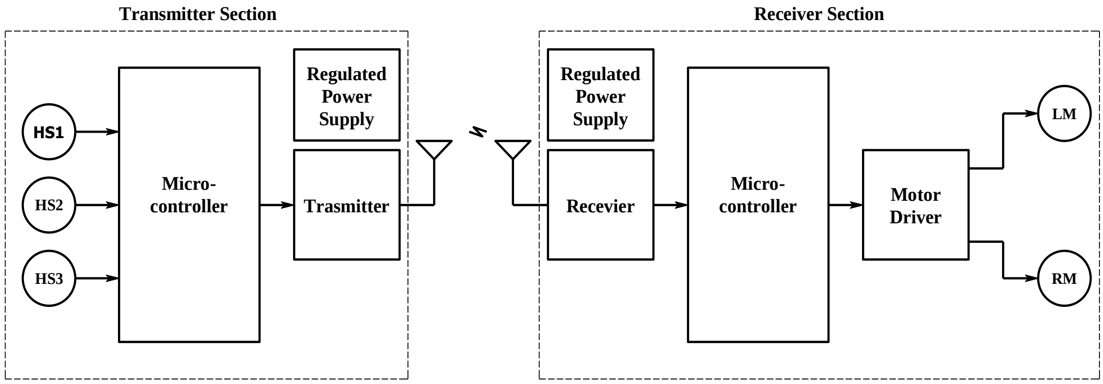

Figure 1: Basic Block Diagram of Tongue Driven Wireless Assistive Technology

Tongue driven wireless assistive technology consists of an array of Hall Effect sensor and small permanent magnet. It translate user's command into control commands by detecting and classifying their voluntary tongue motion by using small permanent magnet, held on the tongue using tissue adhesive or tongue piercing. The magnetic field generated from the magnet will change inside and outside the mouth as the user will move his tongue. These variations are sensed by the three Hall Effect sensors that are placed as an array outside the mouth. Now depending upon the strength of the magnet field the output of the sensor will vary. As the output of these sensors is of analogue type, it should be converted into digital. The three ADC channels of microcontroller are used to convert the analogue signals coming from sensor into digital values. The microcontroller will compare the sensors output with the predefined threshold value and based on the programming in will check user has issued which command. Depending upon the command, microcontroller will send particular characters to the transmitter. Transmitter will transmit the encoded data wirelessly. Receiver will receive the transmitted data, decode it and feed it to microcontroller unit of receiver section. The microcontroller is the main controlling unit that will control the movement of wheelchair. The wheels of the wheelchair model will rotate with the help of DC motors. Based on the input, microcontroller will provide predefined logic to the dual full bridge driver, which is already loaded in microcontroller using Embedded C programming. Driver IC in turn will control the rotation of DC motor (clockwise and anticlockwise rotation) due to which wheelchair can move in left, right and forward direction.

Tongue drive wireless assistive technology has five individual commands that are simultaneously available to the user three directional commands (LEFT, RIGHT and FORWARD) and two selection commands (Stand-by and Active Mode). When driving PWCs, FORWARD is used to move the wheelchair forward, while LEFT and RIGHT are used to turn left and right respectively. To deactivate the system during eating and talking we can switch the TDS from active to stand-by mode, during which wheelchair will remain still.

Experimental Setup

Mouthpiece

The mouthpiece, shown in Figure 2, uses the off-the-shelf commercially available components to evaluate the feasibility and performance of this approach in developing assistive devices**.** The prototype device uses three Hall Effect switch mounted on the hardhat in front of the mouth as shown in Figure 2. The three magnet switches namely left, middle and right switch are linearly arranged. A small disk-shaped permanent magnet is used as the tracer (see Figure 2 inset).

The main purpose of the prototype device was to move the wheelchair model based on the location of a permanent magnet relative to three Hall Effect magnetic switches. An high performance, low power microcontroller (ATmega88, Atmel, AVR), which is the heart of the control or transmitting unit, takes analog signal from each sensor, and convert into digital signal**.** The control unit always compares the digital outputs with a pre-defined threshold value to check which command is issued by the user. This threshold is defined as the minimum sensor output when the magnetic tracer is held at or less than 0.5 cm distance**.** Depending upon threshold condition of different sensor, data will be wirelessly transmitted through ASK transmitter.

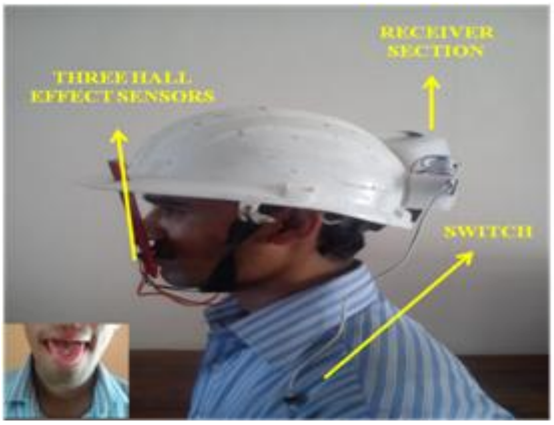

Figure 2: Transmitting Module Implemented on Hardhat, Inset: Small Permanent Magnet Attached on User's Tongue Using Adhesive

The transmitting section and battery is placed on the backward side of hardhat. The transmitting section is operated with the help 9V battery. Subject can activate or deactivate the circuit with the help of switch. If the user wants to talk with someone or eat he can deactivate the transmitting section. The switch is held on the shoulder and the user who can move his neck can switch it on and off by pressing the button with the help on his chin.

Control Hardware and Wireless Link

The Tongue driven wireless assistive technology uses three 3144 sensitive Hall Effect switches (Allegro) mounted linearly on hardhat as shown in Figure 2. A small disk shaped permanent magnet is used as tracer (see Figure 2 inset). A high performance, low power Atmel AVR 8 bit microcontroller namely ATmega88 and ATmega32 has been used as the controlling unit in the transmitter section and receiver section respectively. Wireless transmission has been carried out with the ASK transmitter and receiver, the transmitter can transmit the signal up to 80 metre in line-of-sight. The DC motors were operated with the help of L298 full dual bridge driver which will get the TTL input from microcontroller input/output port. The transmitter section is

Software Used

The main software used to program the microcontroller ATmega88 and ATmega32 was mikroC PRO for AVR. In EAGLE schematic diagram of the transmitter and receiver section was made from which PCB layout was made. PROTEUS was used for simulating the whole design.

PERFORMANCE EVALUATION

Human Subjects

Six able-bodied human subjects participated in the experiments. All subjects were from Government College of Engineering Amravati, comprising of six male with ages from 20 to 26 years. The subjects were right handed and familiar

with English. Subjects were willing to perform the task. All the subjects were novice to tongue drive wireless assistive technology and had no previous experience with this technology before these trails. Also these subjects had no former experience with other assistive technologies.

Experimental Procedure

Detailed instructions were prepared ahead of the trials and provided to the subjects, and then strictly followed to ensure that every subject follows the same procedure.

Magnet Attachment

A permanent magnetic tracer was washed with detergent and tap water, dried, and attached to the subject's tongue, about 0.5 cm from the tip, using denture adhesive. Adhesive is used for attaching the magnet for temporary purpose; if the user wants to permanently attach it he should pierce the magnet on the tongue.

Subjects were allowed to familiarize themselves with the tongue drive wireless assistive technology and magnetic tracer on their tongues for approximately 10 min.

Figure 3: Image Showing the Position of Small Permanent Magnet on Tongue

Command Definitions and Tongue Drive System Training

Subjects were informed about the tongue position in their mouth for each command. The subjects were told to repeat this step for three times to achieve the best command definition and help the subjects remember them. Once the subjects got familiar with command-related tongue positions, they were ready for the training session. Each subject was given 10 minutes for training in that they have used all the commands for controlling the wheelchair.

Task Related Experiment

During wheelchair trials, the subjects were required to drive the wheelchair with their tongue through the track, as shown in figure 4. The figure 4 shows the approximate dimensions of the track with its start and stop point. There were total eight turns in the path.

The track was designed for the subjects to use all tongue drive system control commands and perform various navigation tasks such as making a u-turn, move left, right and forward in a limited space. The subjects were asked to navigate the wheelchair from start point to stop point as fast as they can. Each subject repeated this procedure for five times.

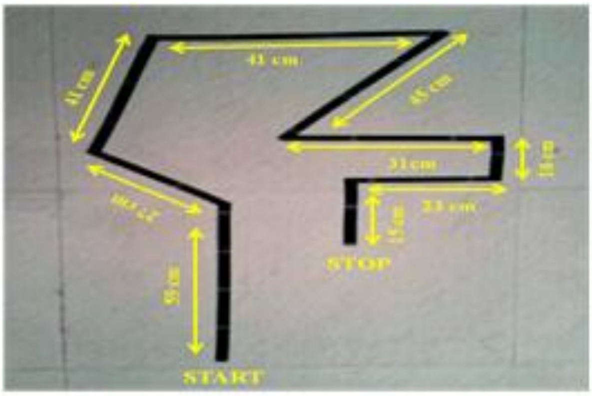

Figure 4: Plan of the Track Used in the Wheelchair Navigation Human Trials using the TDS, Showing the Approximate Dimensions

Experimental Result

All subjects had successfully completed the given task. To analyse the performance of the system two parameters were considered such as completion time and navigation error.

Completion Time

The subjects were told to navigate the wheelchair through the given track from start to stop point as fast as they can. The completion time for each session was noted down and is represented in tabular form (as shown below in table 1).

Table 1: Tabular Representation of Completion Time for Each Subject Over Five Sessions

Session / No. Subjects	Session 1 (In Second)	Session 2 (In Second)	Session 3 (In Second)	Session 4 (In Second)	Session 5 (In Second)
Subject 1	50	43	46	34	39
Subject 2	56	50	45	47	40
Subject 3	52	49	43	46	42
Subject 4	52	47	49	40	43
Subject 5	55	46	47	42	40
Subject 6	49	52	46	45	41

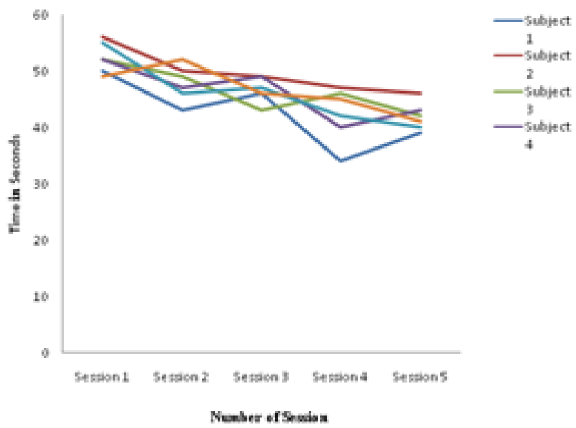

Figure 5: Representation of Completion Time for Each Subject Over Five Sessions

During five sessions, the average completion time decreased from 52.33 seconds in the first session to 40.83 seconds in the fifth session. The improvement was faster from the first to the second session; however, while it slower down from second session to last session. The statistic shows that as the subject get familiarise to system, response time of the subject decreases at the time of turns and subject can navigate the wheelchair model faster.

Navigation Error

When subjects were not able to correctly issue the command that they had intended, they had to issue another command to correct the previous one this can be called as navigation error. Another important thing leading to navigation error was the timing of the commands. For example, to perform a 90° right turn, subject could drive the pwc to a proper position and issue a turn right command at the right time to make a single sharp turn followed by forward when the rotation was close to 90°.onthe other hand, the novice subjects either started turning the pwc too early and too little or too late and too much, in which case they needed to issue a few other turn left and turn right commands to adjust the wheelchair position. This can lead to increase in the completion time. Hence, the number of navigational error done by each subject over five sessions were noted down and represented in tabular form (as shown in Table 2).

Table 2: Tabular Representation Regarding Number of Navigational Error Done by Each Subject Over Five Sessions

Session no / Subjects	Session 1	Session 2	Session 3	Session 4	Session 5
Subject 1	7	6	3	3	3
Subject 2	10	7	4	5	4
Subject 3	8	7	4	5	3
Subject 4	8	6	7	4	4
Subject 5	10	7	7	4	3
Subject 6	8	9	4	4	3

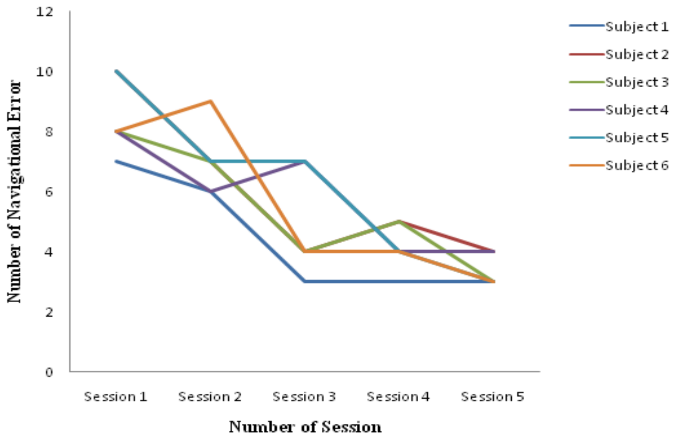

Figure 6: Representation Regarding Number of Navigational Error Done by Each Subject Over Five Sessions

The graph of number of navigational error versus session number is shown in graph 2. From the graph it is seen that there is significant decrease in the number of navigational error done by the subject from first session to third session. After the third session, the numbers of navigational errors remain constant. Some time the subjects were not able to take sharp turns properly. One subject has said that it would be good if there was small display in front of the user so that they should known which command has been issued.

Questionnaires

After completing the task related experiment each subject were asked the questions related to their driving experience. Five question were asked which were based on whether the user need mental effort to remember the tongue position; whether the user is able to accurately guide the wheelchair; does they perceive tongue fatigue or jaw fatigue and does wheelchair model move smoothly. Subjects responded to 5 questions in the five-point likert scale to subjectively evaluate their tongue drive system experience. From the graph 4.1.7 it can be concluded that subject required little mental

effort to remember the tongue position, perceived little tongue and jaw fatigue. They required some attention for accurately guiding the wheelchair also subject felt the movement of wheelchair some what smooth.

Table 3: Subject's Response to the Questionnaires

Sr. No	Questionnaire	S1	S2	S3	S4	S5	S6
1	Mental effort to remember the tongue position- 1: A lot and 5: A little	4	4	5	4	4	4
2	Accuracy guiding wheelchair- 1: Very difficult 2: Need some attention and 5: Very easy	2	3	3	4	3	3
3	Smoothness of wheelchair- 1: To jerky and 5: Very smooth	4	3	3	2	4	3
4	Perceived tongue fatigue- 1: Not at all tired and 5: Very tired	3	3	2	2	3	2
5	Perceived jaw fatigue- 1: Not at all tired and 5: Very tired	2	2	2	3	2	2

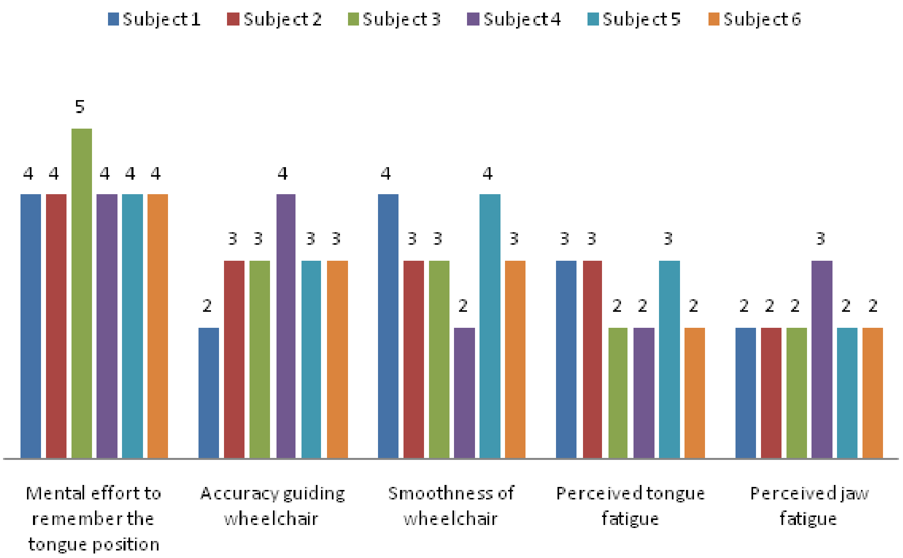

Figure 7: Representation of Subject's Response to the Questionnaires

The main purpose of this study was to observe the tds learning process, including the subjects' initial performances, improvement rates, and overall achievements through five sessions.

CONCLUSIONS

Tongue drive wireless assistive technology works by tracking the movements of a small permanent magnet secured on the tongue with the help of an array of Hall Effect sensors. The sensor outputs are a function of the position-dependent magnet field generated by the permanent magnet. This system can potentially benefit people with severe disabilities by enabling them to control their environments, access computers, and operate power wheelchair using their tongue motion. The performance of the system was evaluated by carrying out task related experiment carried out by six able-bodied subjects. For evaluating the performance two parameters were considered namely completion time and number of navigational error. Subjects navigated the wheelchair model over the track for five sessions. A significant performance improvement was observed in the second session. This improvement continued over the next three sessions but at a slower pace. This technology provides faster, smoother and more convenient proportional control as compared to many existing assistive technologies. Also tongue and jaw muscle does not fatigue easily. Other advantages of the Tongue Drive system are being unobtrusive, low cost, minimally invasive, flexible, and easy to operate.

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